LCA Case Studies

A Comparison of Two Different Approaches to Inventory Analysis of Dairies

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Abstract

Two different methods for Life Cycle Inventory (LCI) applied to the dairy industry was performed at two dairies. In the simplified method, total environmental loads from a dairy was registred and allocated to liquid milk. Energy and emissions are measured for each process step for the detailed method. Both methods have advantages and disadvantages. The simplified method captures all energy and emissions of dairy processing, but treats the dairy as a "black box". The energy consumption was found to be 1,27 MJ/l and 2,55 MJ/l for the two dairies. By use of the detailed method it is easy to "loose" information, and it is very time consuming. The energy consumption was lower than for the simplified method. The environmental loads can on the other hand be divided on the different process steps. The main conclusion is that choice of method depends on the purpose of the LCA-study.

Keywords: Biochemical oxygen demand (BOD), diaries, LCIA; BOD, diaries, LCIA; diaries, LCIA; emissions, diaries, LCIA; energy consumption, diaries, LCIA; LCA, diaries; LCIA, diaries; Life Cycle Assessment (LCA), diaries; Life Cycle Inventory Assessment (LCIA), diaries; milk, dairies, LCIA

1 Introduction

In the dairy industry refrigerated milk is received, pasteurized and processed by different technologies to give a wide range of products. Energy is used for processing of the milk, heating and cooling of rooms, packaging and for cleaning of the process equipment. Water is used in the processes as well as for cleaning. Upon rinsing and cleaning of the process equipment some milk is mixed with water and discarded to the sewage.

Life Cycle Assessment (LCA) is a tool to quantify the environmental impacts associated with for example, the processing of milk in the dairy industry. LCA consist of 4 phases, Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation (ISO, 1997). Lindfors et al. (1995) and SETAC (1993) have also stated frameworks for LCA and inventory.

The LCA methodology has often been used for dairy packages (Oterholm et al., 1994; Tillman et al., 1991; Mekel et al., 1990; Baumann et al., 1993; Ponsford, 1993; Zentralverband Schweizerischer Milchproduzenten, 1991), but very rarely for dairy farming (Meeusen, 1996; Møller and Høgaas, 1997) and dairy processing of milk (Vorre, 1994; Rydberg et al., 1995; Grøtan, 1996; Glende, 1997; Møller and Høgaas, 1997).

There are more than one way to carry out an LCA, and the choice of method depends on the purpose of the project.

The goal of this work is to evaluate and compare two different methods to carry out an inventory (or an LCI (Life Cycle Inventory) where all the steps of the life cycle of milk is assumed to be identical except for the dairy processing) for the dairy industry where the correctness of carrying out a so called simplified inventory (here defined as the dairy is looked upon as a "black box") is compared with a more detailed inventory method. In this work the two methods are called the simplified and the detailed method. A basis for how to execute an LCI or an LCA applied to milk processing in the dairy industry will be suggested here.

The first method presented (the simplified method) is suitable to assess the entire life cycle of the milk (from cradle to grave) to find the environmental impact associated with the dairy handling and processing of the milk. Thus, dairy processing may be compared to the rest of the life cycle of milk. Several LCAs have shown that the agricultural steps of the life cycles of animal based food products often contribute more to the environmental impacts than the processing industry (Møller and Vold, 1995; Weidema et al., 1995). In Møller and Høgaas (1997) the dairy processing including the distribution show high contributions to energy consumption and emissions to air.

The total use of resources and the total emissions at the dairy plant are allocated to the product studied (liquid milk) by the simplified method. The method may also be used for a first screening in a more detailed study and for registra-

tion of the emissions and the consumption of energy and water if dairies or food processing plants are to be compared. Use of the method will not give information about what is going on in the different process steps in the plant.

The second method, "the detailed method", uses the life cycle approach to, in detail, investigate all the dairy activities. The goal may often be to find the "hot spots" (where the impacts on the environment are largest) inside the dairy This method may also be used when the entire life cycle of milk is taken into account.

A case LCA-study considering the production of 1 litre of liquid milk at two dairies in Norway was carried out for both the methods described. The case study only covers the dairy operations, which is a small part of the life cycle of milk. The other steps of the life cycle was assumed to identical for the two dairies. The life cycle approach is used to determine the use of resources and emissions from the two dairies.

2 Methods

The investigated dairies:

- Dairy A is a middle sized Norwegian dairy. The amount of processed milk per year is about 20 mill litres. The products produced are liquid milk, cream and cultured milk.
- Dairy B is a very small dairy, processing only 8 mill litres of milk per year. Liquid milk, cream, cultured milk and butter are produced. Dairy B also transfer a considerable amount of skimmed milk, arising from production of butter, to other dairies for further processing.

Total environmental impact from the dairy has been analysed and allocation has been performed to find the contribution to the environmental impact from liquid milk by the simplified method. Allocation and system boundaries are thus of great importance.

In Figure 1, a general flow chart of the milk through this dairies is shown. The boxes in bold lines are common for both dairies. At Dairy A the milk is packed in both containers and crates while at Dairy B the milk is handled in a separate cooler before filling. The simplified and the detailed methods described below were used to analyse the environmental impact of the production of liquid milk in the two dairies.

2.1 The simplified method

If just liquid milk and not all products produced at the dairy plant is considered, allocation of the environmental loads between the different products must be performed. Traditionally allocation problems are associated with multi-output "black box" processes, i.e. when more than one product is produced and some of those products flows are crossing the system boundaries (Lindfors et al., 1995). A dairy plant is an example of a multi-output process.

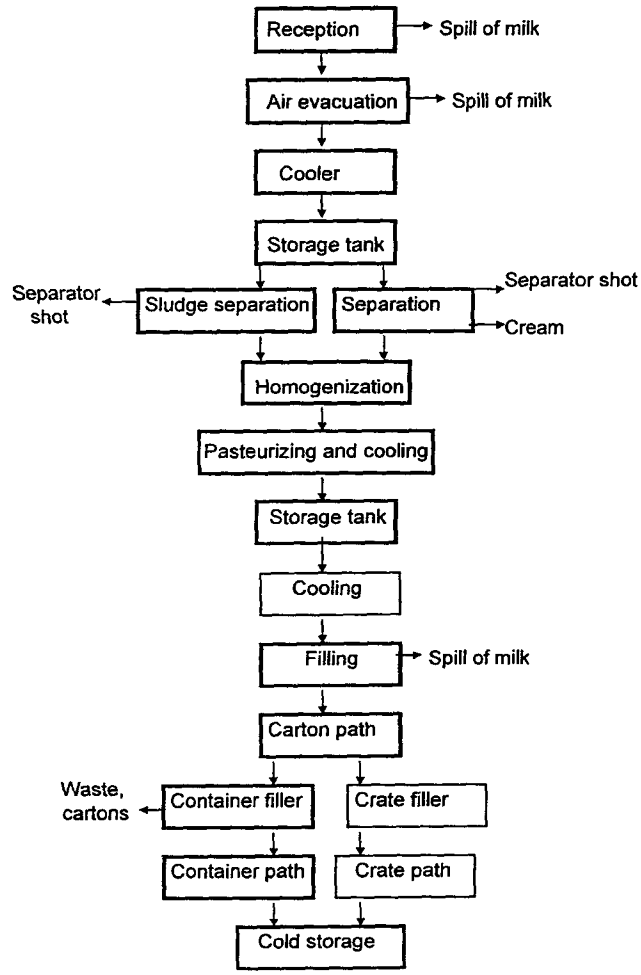

Fig. 1: Dairy processing of liquid milk

In a dairy, allocation can be made by economical value or by a physical parameter as mass or volume. This will probably not be correct, because some products contribute more to the emissions to water than other products. More viscous products will stick to pipes and equipment and thus follow the waste water to the sewage. Viscous products are normally more processed, and energy consumption usually increases as the processing increases.

In this work the allocation is based on natural causality and the permitted emissions based on a large number of measurements given by Norwegian Pollution Control Authority (SFT) were used as an allocation key for all the considered emissions, energy consumption and use of resources. They are given as the amount of kg BOD_7 (biochemical

oxygen demand), which the plant is allowed to emit per ton produced of the different products. In **Table 1** the figures for the dairy industry, given by SFT, is shown. Allocation based on natural causality are recommended by both LINDFORS et al. (1995) and ISO (1997).

Table 1: Permitted emissions of kg BOD7, per ton product from the production of various dairy products given by Norwegian Pollution Control Authority (SFT)

Product	kg BOD_7/ton product
Transfer milk	0,4
Liquid milk	1
Cream	1
Cultured milk	2
Yogurt	4,3
Sour cream	7
Butter	8,5
Cheese	15 - 17

It was chosen to use the permitted emissions to water as an allocation key for all the parameters. The energy and water consumption are assumed to increase as the permitted amount emissions of BOD_7 increase. The specific energy consumption or water consumption per unit of product could also has been used as an allocation key. HØGAAS (1998) shows that there are only small differences when liquid milk is considered.

The table shows the emissions permitted for each product. Continuous analysis of the waste water from different dairies have shown that this figures is very close to the real value of emissions from the different product investigated by Norwegian Dairies Association (STRAND, 1995, personal communication). By use of this method the dairy processing plant is looked upon as a "black box".

The organic matter in the total flow of waste water leaving the dairy was registered daily for two weeks. Equipment for these analysis was available at the dairies. Water consumption was registered by the total flow of water into the dairy. The total energy consumption at the dairy, divided between thermal energy and electricity, was measured and registered. Energy consumption of the social rooms, the offices and the cafeteria were included by use of the energy meter which measures the total use of energy for the whole plant.

In Norway the dairies alternate between electricity and oil for heating of water and rooms according to the price of the energy source. When these measurements were carried out, electricity was used as source for thermal energy. The figures for both energy consumption and emissions to water were allocated by use of the officially permitted emissions for each product.

2.2 The detailed method

If the results show that the dairy only is responsible for a small part of the total environmental burdens of the life cycle of milk, more resources may be used to investigate the step of the life cycle which contributes most. If the dairy plant, on the other hand, is found to contribute much to some environmental impacts, there may be reasons for further investigations of the dairy. Then it is possible to localize the processes in the dairy ("hot spots") which are the major contributor to the environmental impacts by use of the detailed method.

The stated effect and capacity of each engine and pump was registered to assess the energy consumption. The emissions to water from the rinsing phase was measured by collecting the waste water leaving to the sewage. The amount of waste water was measured and the composition analysed. The energy loss to sewage was calculated by the temperature of the water leaving to sewage compared to the temperature of the water entering the dairy.

With regard to auxiliary functions as i.e. ice-water for cooling, the effect of the engines and the estimated process time each day were used to calculate the energy consumption. The efficiency of the electrical boiler was taken into account with regard to the thermal energy.

The energy consumption was divided on cleaning processes and other dairy processes, and also between the different process step in the dairy plant.

3 Results

Figure 2 shows the energy use, the water consumption and the emissions of BOD_7 from Dairy A. The first bars show the total environmental burdens of liquid milk calculated by means of the detailed method, divided in cleaning processes and other processes. The last bar in each group is the total consumption and emissions allocated to liquid milk by the simplified method.

The figure shows that the total emissions and energy and water consumption found by the simplified method generally has higher values than the total amount calculated by the detailed method. The emissions and energy and water consumption of Dairy B showed the same pattern as Dairy A.

The energy consumption based on the simplified method was found to be 1,27 MJ/l liquid milk for Dairy A and 2,55 MJ/l for Dairy B. The ratio of electricity was respectively 18% and 14%. The allocated measured values of energy use found by the simplified method shows that the small Dairy B consumes more energy per litre milk processed.

In **Figure 3** (→ *p. 213*) the detailed method is used to calculate the energy consumption. The energy, divided in thermal

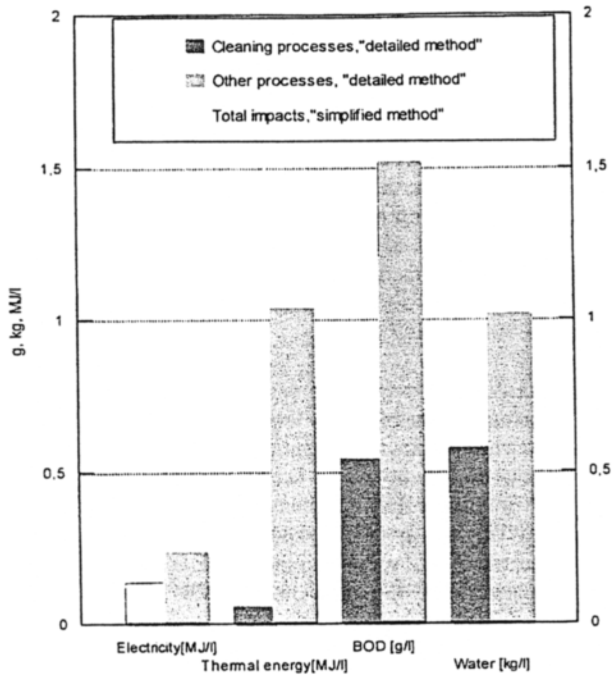

Fig. 2: Environmental impacts per litre liquid milk calculated by the *detailed* method divided on cleaning processes and other processes and the total impact per litre liquid milk found by the *simplified* method for Dairy A. (Environmental impacts considered: BOD_7, water consumption and energy consumption divided on thermal energy and electricity)

energy and electricity, is shown for each process step of the production of liquid milk at the dairies. Milk reception also includes the cleaning of the tank lorry. The term 'product tanks' includes cleaning of tanks, pipes to the filler and the ventilation in the process room.

The figure shows that the separator, the homogenizator and the plate heat exchanger use much energy, both thermal and electrical. The refrigerator storage of the packed milk also uses much electricity. This figure shows that the electricity consumption per litre of processed milk is lower for Dairy A than for the small Dairy B. This is in accordance with the results obtained from the simplified method presented above. The thermal energy is on the other hand almost the same for both the dairies when calculating by the detailed method.

4 Discussion

There are advantages and disadvantages associated with both the methods. The main advantage of the simplified method, in addition to quick execution, is that absolutely all the energy and water used and all the emissions to water are accounted for, including energy used for heating of rooms and water used for cleaning of floors and outside cleaning of equipment. Also the energy and water consumption of social rooms, offices, cafeteria and laundry are accounted for. The inclusion of the energy consumption for additional activities may not be a disadvantage, because these activities are undertaken as a consequence of the production.

A disadvantage of this method is the difficulties of allocation. It is possible that the production of the other products (cultured milk, butter, and milk sent to other dairies after pasteurizing) contributes more to waterborne emissions than suggested by the permitted emissions. According to this, too much environmental loadings may be allocated to the fresh milk and then the allocation may not be correct. The production of cultured milk at the larger Dairy A is very small. Only 3% of the milk is used for cultured milk. A small production emits more per litre than a bigger production (GLENDE, 1997).

By use of this method the dairy is treated as a "black box". It is impossible to separate the environmental loads between the different process steps in the dairy.

In contrast to the simplified method the detailed method allows separation of emissions, energy and water consumption on the different process steps. LCAs or LCIs based on the detailed method are time consuming. It is necessary to investigate every step in the entire production line, including a very detailed collection of data of each engine, pump, process equipment and cleaning processes. In **Table 2** (→ *p. 214*) the number of working hours for each method is assessed and how to collect the data is described. To get the same quality of the data, the measurements should be performed for at least one week. The table shows that the detailed method require a lot more of work. The meters used to measure for the simplified method is usually installed in the dairies. The detailed method also require some work to install equipment before the measurements can take place.

The main disadvantage of the detailed method however, is that it is very easy to "loose" energy and water consumption. Especially the thermal energy used for heating of rooms and water used outside the CIP (cleaning in place) station is "lost". The equipment may not be operated at the suggested effect and capacity, and may consume more or less energy than prescribed. It is possible to measure the actual consumption of energy of each pump and engine however, the benefit of such measurements was assumed to be rather limited.

Figure 2 shows that the values of electricity per litre of processed milk is the parameter covered best by the detailed method. In principle the two bars in each group show the same emissions and consumption, so they should be comparable. The figure also show that the detailed method is less useful when it comes to measurement of the use of thermal energy, as the energy used for heating of a considerably amount of water and rooms is not included. The loss of energy through radiation and convection from heating of the equipment by the cleaning processes and from the tanks of the cleaning solutions are not registered. Neither the energy used by the laundry nor in the social rooms and the offices is taken into account. With regard to water con-

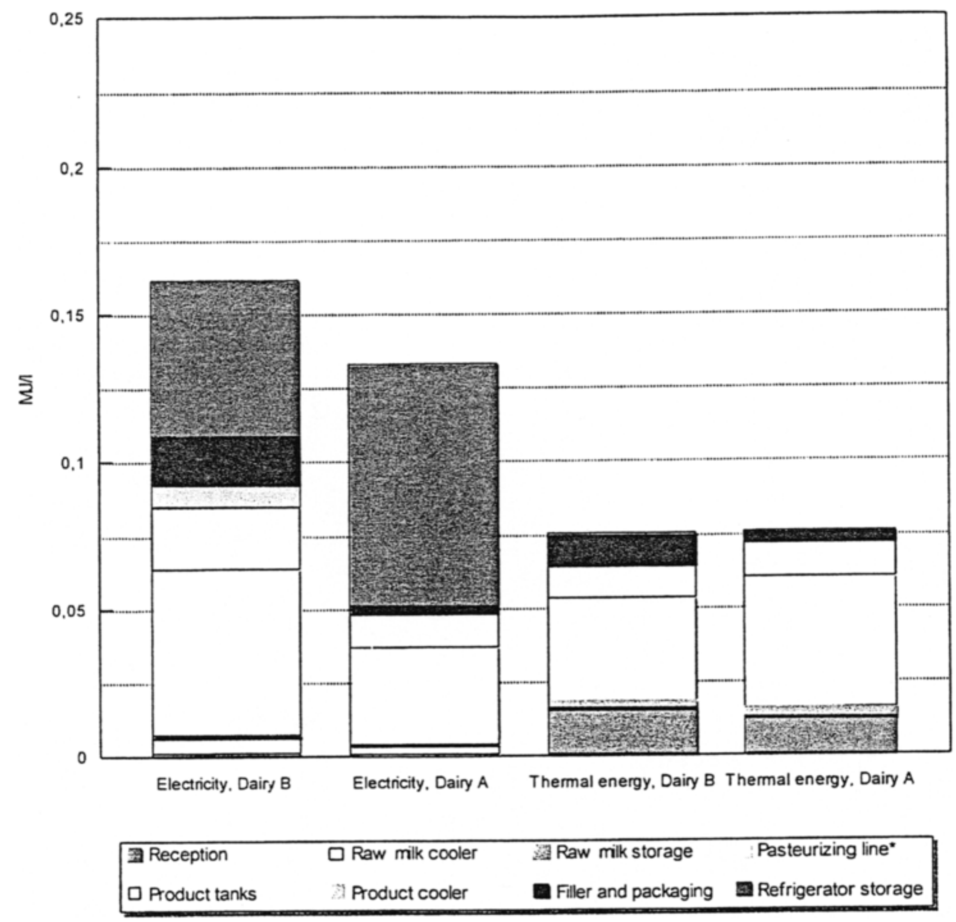

Fig. 3: Energy consumption divided on thermal energy and electricity for each process step at the dairies obtained from the *detailed* method; * separator, homogenizator and plate heat exchanger

sumption only the waste water leaving to sewage from the rinsing phases in the cleaning processes is included.

Emissions to water mainly occur from the rinsing of the equipment, the first part of the cleaning in place (CIP) program. Spillage of milk from the milk reception and filling of liquid milk also contributes to the waterborne emissions. The data of emissions to water from the spillage are estimates, which may not be accurate.

Another source of error associated with the detailed method is the use of energy by the refrigerator storage. In the detailed method, the optimal values of energy consumption of the central refrigeration plant is used, but the use of energy by the refrigerator storage is affected by auxiliaries. Main auxiliaries are condenser and evaporator fans and pumps, and secondary refrigerator-air distribution pumps and fans. There are also "secondary" auxiliaries, other equipment which is not directly associated with the refrigeration plant but which affects its performance, such as lights in cold stores and defrost equipment in cold rooms.

Also heat gains from poorly maintained insulation, fans in cold spaces, heat ingress from open doors, pumps for the circulation of chilled fluids and excessive defrosting affects the consumption of energy are not considered by the detailed method (DALZELL, 1994).

To include the loss of thermal energy through radiation and convection from heated equipment in the detailed method, a logging station could be used. The flow and the temperature of the rinsing water, cleaning solution and hot water is measured (Norwegian Dairies Association, 1995). A logging station will capture the energy loss due to heating of the cleaning objects, but still the heating of water for cleaning outside CIP and the heating of rooms will be "lost".

In this paper only a few environmental parameters are considered. The differences in the methods and not the specific results are of main interest. The results from the two dairies will however be discussed to illustrate the methods.

Table 2: An assessment of the number of working hours and how to collect the data for the two methods

	Simplified method	Detailed method
Electricity	Reading of meters, ordering of daily electricity consumption from the supplier, *0,5 hours a day*	Reading of the stated values for consumption of electricity of each engine and pump, *5 hours* Consider the working hours of the equipment, *6 hours a day*
Thermal energy	Ordering of daily electricity consumption alternatively consider the total oil consumption, *0,5 hours a day*	Collection of waste water from the cleaning process of each object, measuring the temperatur and volume, take a sample for analyzing for organic comppounds, estimating of spillage from reception and filling, *6 hours a day*
Water	Reading of meter, *5 minutes a day*	
Waterborne emissions	Reading of meter, sample for analyzing for organic compounds, *0,5 hours a day*	

Almost all the electricity is used for other processes than the cleaning processes. Electricity is only used for the cleaning processes by the pumps pumping the cleaning solutions to and from the cleaning objects.

By the simplified method it was found that for both the consumption of electricity and thermal energy, the small Dairy B had higher consumption per litre of milk processed. Especially the consumption of thermal energy was high at Dairy B compared to Dairy A. All the equipment have to be started and cleaned daily by use of thermal energy, without regard to the size of the production.

The consume of thermal energy calculated by the detailed method is on the other hand almost equal for the dairies, as can be seen in **Figure 3**. This was not expected, but only a very small part of the thermal energy consumed is captured by the this method, which influences on the results.

Figure 3 shows the use of energy calculated by the detailed method, divided into different steps of the production of liquid milk. The separator, homogenizator and plate heat exchanger are aggregated because they are cleaned together. In the filling operation also the carton paths and the container filler are included. The figure shows that the pasteur line and the refrigerator storage has high demand of energy. At Dairy A the consume of thermal energy of the pasteur line is considerably. A reason is a very high amount of rinsing water leaving to sewage causing loss of energy from the dairy.

At the small Dairy B only 53% of the received milk is used for processing of liquid milk. At Dairy A the percentage is 97. The energy consumed regardless of the size of the production, as cleaning of the milk reception line, the raw milk storage tank and the pasteurizing line, is at the dairies shared between the different products based on a mass allocation. At these process steps the milk processing is independent of the final product.

For both dairies, the allocated emissions of BOD_7 to water calculated by the simplified method are higher than the emissions calculated by the detailed method. The loss of milk may be higher than the estimated values. The emissions in the rinsing water also seems to vary considerably (STRAND, 1995, personal communication), which also have been seen from the measurements at the dairies.

5 Conclusions

The two approaches have different purposes and are not directly comparative. The method to choose for execution of an LCI or an LCA for dairy processing depends on the goal of the study. In **Table 3**, a suggestion for choice of method depending on the purpose of the study is shown.

The table shows that the methods mainly are to be used in different ways. The main advantage of the simplified method is the time aspect. The method does not require as much work as the detailed method: All the impacts are accounted for by the simplified method, but on the other hand the basis used for allocation, as the permitted emissions, may be a source of error. The method makes it difficult to find the "hot spots" and where to put in resources for improvements. The dairy is a "black box".

The advantage of the detailed method is mainly the opportunity to find where in the dairy processing plant improvements should be done. It is often in this step of the life

Table 3: A suggestion for choice of method for different purposes

Purpose	The simplified method	The detailed method
To study the total life cycle of milk	x	(x)
To find "hot spots" inside the dairy		x
To find the main contributor to the environmental loads of the life cycle of milk	x	
To compare different dairies	x	x
To assess the technology used		x
To evaluate new technologies		x
Screening	x	

cycle the dairy industry is able to do something. They do not have the same opportunity to influence on the other parts of the life cycle. The disadvantages are, as mentioned above, the requirement of time, and that some information will be "lost".

It is important to notice that none of the methods exactly will describe the dairy processing. There are sources of error in both methods.

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